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Synchrotron-Self Compton Spectral Evolution of PKS 2155-304

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Abstract. The high frequency peaked blazar PKS 2155-304 is one of the brightest and most intensively studied prototype of BL Lac objects. Gamma-rays from PKS 2155-304 have been detected from the MeV to TeV ranges. We computed a synchrotron self-Compton (SSC) model, based on the temporal behavior of the particles distribution, responsible for the high-energy emission. Using the available simultaneous multi-wavelength data, we simulated the overall spectral energy distribution (SED) and the spectral variability of this source.

1. Introduction

The overall spectral energy distribution (SED) of blazars show a two-bump structure, where the lower frequency hump is peaked either in the IR/optical (low frequency peaked LBL or "red" blazar) or in the UV/X-ray bands (high frequency peaked HBL or "blue" blazars), and is believed to be produced by synchrotron emission, while the higher frequency component should be due to inverse Compton (IC) scattering of soft photons. In the standard inner-jet scenario, synchrotron radiation and IC scattering were usually interpreted as due to diffusive shock acceleration of charged particles within a plasma jet, which itself moves at relativistic speed and points toward the observer. In this elegant view, the same relativistic particles up-scatter by IC, the seed photons produced by synchrotron radiation (synchrotron Comptonization or synchrotron self-Compton, SSC, process). We implemented an SSC time-dependent model for the HBL (and TeV-blazar) PKS 2155-304 (z=0.116). This blazar is a strong γ-ray emitter, and one of the more luminous at UV and X-ray wavelengths. Because of its brightness, it is one of the best targets of multiwavelenght campaigns, and the data produced in this campaigns, represent a good test bench to constraint source models, parameters and simulated SEDs.

2. Model and simulations

To constraint our model we used three multiwavelenght campaigns on PKS 2155-304. The first large campaign, performed in May 1994 (see Fig. 1), using radio-optical-nearIR ground based observations and IUE, EUVE, ASCA data, together with the GeV detections obtained in 1994 by EGRET, on board of the Compton Gamma-Ray Observatory (CGRO) (Urry et al. 1997, Pesce et al. 1997, Pian

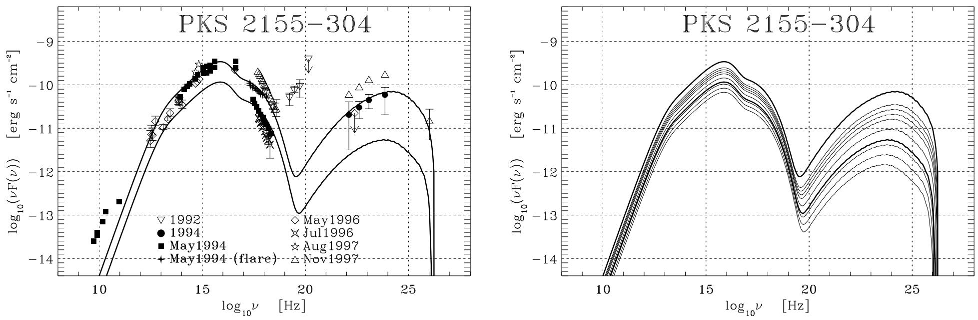

Figure 1. Attempts to fit the SED of PKS 2155-304, using the data of the May 1994 multiwavelength campaign. In the right panel the temporal evolution.

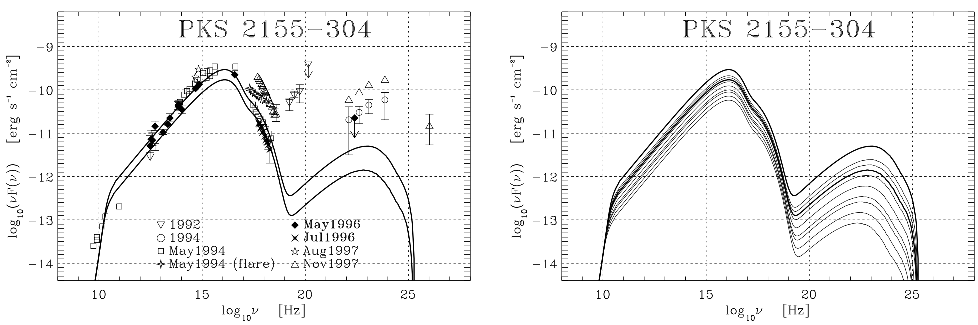

Figure 2. Attempts to fit the SED of PKS 2155-304, using the data of the May 1996 multiwavelength campaign and the July 1996 ASCA data. In the right panel the temporal evolution.

et al. 1997). Then we took the data of the May-June 1996 campaign (see Fig. 2), carried out, in particular, with the infrared (2.8-100μm) observation of ISO (Bertone et al. 2000). Moreover we used the September-November 1997 TeV positively detections by the Cerenkov Telescope Mark 6 (Narrabri-Australia) and by EGRET (Chadwick et al. 1999, Vestrand & Sreekumar 1999, Kataoka et al. 2000, Chiappetti et al. 1999) (see Fig. 3). This blazar was also positively detected at MeV regimes by OSSE in 1992 (on board of CGRO).

We considered a distribution of relativistic electrons confined by a tangled magnetic field **B**, into a non-thermal flaring knot of plasma (of dimension R) in the jet of PKS 2155-304. The globule is subordinated to the injection of shocked and freshly energetic electrons, radiatively cooling. This can be described with an appropriate truncation of the exact kinetic relations, adopting a diffusion approximation that leads to a random walk in the energy space of electrons. Hence we used a mere one-dimensional diffusion-advection-like kinetic equation (Ciprini 2002) for the electron number density $N_e(\gamma, t)$ [cm^{-3}], in order to describe the time-dependent evolution of the electron distribution into the emitting volume. The solutions of this type of equations, are very sensitive to initial conditions, boundary conditions, to injection and losses forms. The

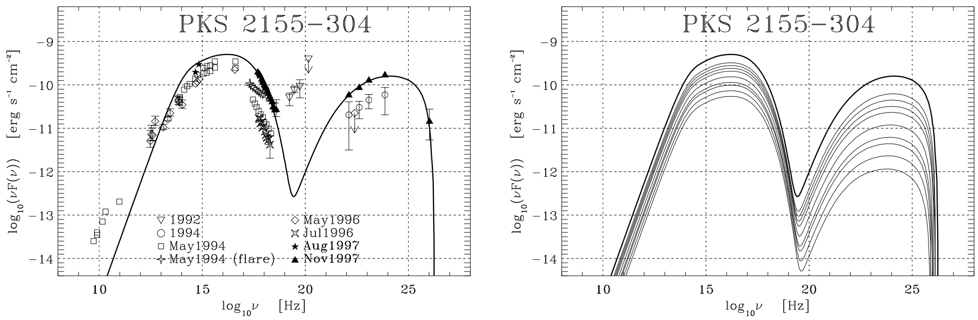

Figure 3. Attempts to fit the SED of PKS 2155-304, using the datat August-November 1997. In the right panel the temporal evolution.

Table 1. Values of the parameters used in the simulations. γ_{min}, γ_{max} are the energy limits of the injected electron distribution. γ_{break} is the energy at the knee and α_1, α_2 the power indexes of the injected broken power law. R is the size of the flaring knot embedded in a tangled magnetic field of mean intensity B (in Gauss). $\mathcal{D}$ is the Doppler beaming factor of the knot. t_{esc}/t_{cr} is the ratio between the electrons escape time and light-crossing time. The number density was taken the same for the three fits: $N_e = 10^6$ [cm^{-3}]. Fig. 1 represents the fit of May 1994 multiwavelength campaign (radio-nearIR-optical-IUE-ASCA-EGRET), where the lower SED in the left panel is the evolved temporal stage, of the upper SED, at $t = 2.2t_{cr}$. Fig. 2 reports the fit of May 1996 campaign (ISO-optical-EUVE-EGRET) and July 1996 ASCA data, where the lower SED in the left panel is the evolved temporal stage, of the upper SED, at $t = 1.6t_{cr}$. Fig. 3 represents the fit of August 1997 optical data and November 1997 campaign (RXTE-EGRET-Mark6).

Figure	γ_{min}-γ_{max} ($\times 10^4$)	γ_{break} ($\times 10^4$)	α_1-α_2	B [G]	R [cm] ($\times 10^{16}$)	t_{esc}/t_{cr}	$\mathcal{D}$
1 (May94)	0.065-1000	2.8	2-2.5	0.2	1.6	1.8	30
2 (May96)	0.001-100	3.5	1.85-2.2	0.45	4.9	1.8	16
3 (Aug97)	0.14-80	1	2.3-2.4	0.55	1.15	1.3	25

overall dynamics adopted is similar to other previous works: (e.g. Kataoka et al. 2000, Li & Kusunose 2000, Chiaberge & Ghisellini 1999, Kirk et al. 1998).

The energy distribution injected, was assumed as a stationary broken power law (acceleration via a two-step process or a composite electron population), between γ_{min} and γ_{max}, with an high energy exponential cutoff (roll-off of the energy distribution), in the form: $Q_e(\gamma) = Q_0\ \gamma^{-\alpha}\ e^{-\gamma/\gamma_{max}}$. The particles population, cools by synchrotron and IC scattering. Time light travel effects have been taken in account, for the convolution of the spectra produced at different distances in the source. An uniform tangled magnetic field of intensity B was considered, even if a small-amplitude plasma turbulence (e.g. Böttcher et al. 1997) could be superimposed. The ensemble synchrotron spectrum was integrated by the calculated electron distribution at any given time, and then Comptonized by the interaction with the energetic electron distribution. Finally the produced spectra were transformed to the observer, through the Doppler boosting factor $D = [(1+z)\Gamma(1-\beta\cos\theta)]^{-1}$ of the flaring blob (where Γ is the bulk Lorentz factor and θ the angle respect to the observer).

In Figures 1, 2 and 3, are represented our three fit attempts, with their temporal evolution. The parameters, with their values, are listed in Table 1. The observed spectra of PKS 2155-304 was simulated quite well at high energies. The radio flux is believed to originate also from stationary, different and far components, respect to the rapid variable flaring knot modelled, doing the discrepancy.

3. Conclusions

The values of the parameters are in agreement with previous models (e.g. Kataoka et al. 2000). The dimension of the flaring region R is on the order of 10^{16} cm, the magnetic field between $0.2-0.6$ G, and a relatively high Doppler factor between $15-30$ seems characterize this TeV blazar. The monotonic course with the frequency of the various X-ray spectra, suggest a small variability in the synchrotron peak frequency, and indeed in our simulations the synchrotron peak is always in the UV bands. This model seems to be a feasible tool, to study the global energetics and the rapid high energy variability, not only in PKS 2155-304, but in each blazar dominated by the SSC process.

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